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Investigating the Simultaneous Effect of Macro Fly Ash and Oak Bark Ash on Mechanical Properties of Concrete

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A B S T R A C T

Due to the increasing use of concrete, researchers and engineers are constantly tried to improve its mechanical and physical properties as well as its efficiency. Hence, they have made use of the most diverse products and the most modern concere technologies. In the present study, oak bark ash and macro fly ash have been used as the most widely used pozzolans in the concrete industry. The parameters of concrete and the percentages of materials used in its structure remained constant, but different percentages of oak bark ash and macro fly ash have been added to the mix design. Brazilian method and bending strength of concrete was applied. The parameters of concrete density, concrete consistency, compressive strength, and tensile strength have been investigated..Therefore, the existing materials required necessary tests; based on obtained resulted, an optimal design for the concrete mix was introduced from which the necessary specimens were taken into consideration. Then, oak bark ash was used as an additive, in proportions of 0.2 and 0.4% by the total weight of cement, and macro fly ash was used to replace cement as a variable in various proportions of 5, 10, 15 and 20% by total weight of cement. Based on the existing variables and the control design, a total of 15 groups of mix designs were introduced. The statistical population includes 45 cubic specimens (15×15×15), and 45 cylindrical specimens (15×30) for tensile strength test using Brazilian method. Also 45 bending beam specimens having dimensions of 10×10×50 were examined. Finally, after analysis of the obtained results, we dentified the superior mix design had the best performance and that both additives affected all studied parameters, including concrete consistency, density, compressive strength, tensile strength, and bending strength of concrete. However, macro fly ash had a great effect on the conrete strength. The obtained results also indicated that excessive use of any additive could have adverse effects on the mechanical properties of the concrete.

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INTRODUCTION

The construction industry is growing at a very fast rate and modern technologies are developing to overcome various barriers in this industry. Concrete is one of the main materials used in this industry and may be made from different types of cement as well as pozzolans, kiln slag, admixtures, sulfur, additives, polymers, fibers, etc. Furthermore, the way concrete is made may depend on how heat, water vapor, autoclave, vacuum, hydraulic pressures, and various compressors are used. In line with scientific developments and advances and the emergence of various technologies in the last century, our knowledge about concrete and its properties has significantly widened. Nowadays, different types of concrete are used which are made of different materials, each with its specific properties and applications [1]. To construct a building or structure, construction contractors assess the advantages of construction materials and substances and choose the best among them according to their quality, strength, and cost. The high strength of concrete has made it one of the principal construction materials. Since

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architects and builders are interested in sustainable development, currently, sustainable materials and materials that have minimal impact on the environment are produced and used [2]. Chemical additives are produced by processing, mixing, or blending organic and inorganic materials in a chemical process and are added to the mixture in powder or liquid forms, and in small amounts, usually up to 5% of the weight of cement, at the time of construction and mixing or just before pouring concrete. Mineral additives, whether naturally occurring substances or industrial by-products, could be divided into three categories: neutral materials, pozzolans, and cement-like materials.

Ramezanianpour et al [3] studied rice husk ash (RHA) as a by-product of the agricultural waste which contains high amount of silicon dioxide (SiO_2) were mixed with cement to improve physical and chemical properties of concretes by incorporating optimal percentage of RHA. The compressive strength, splitting tensile strength, modules of elasticity, water permeability and rapid chloride permeability test were conducted. Results showed that concrete incorporating RHA had higher compressive strength, splitting tensile strength and modulus of elasticity compared with the control concrete. Kanthe [4] studied the effect of superplasticizer on strength and durability of rice husk ash concrete. Rath et al. [5] investigated on early age shrinkage of concrete with binary and ternary combination of fly ash and pond ash with addition of glass fiber. Kanthe et al. [6] conducted an investigation on stength of the concrete by addition of fly ash and rice husk ash. In addition, RHA as an artificial pozzolanic material enhanced the durability of RHA concretes and reduced the chloride diffusion. Riyad et al. [7] studied the effect of fly ash content on mechannical properties of stabilized soil at southwestern region of Bangladesh. To improve the properties of cementitious mixtures, they are generally added to concrete during mixing in volumes greater than 5% of the weight of cement [8, 9]. Fly ash is extracted from the exhaust gases of kilns with coal fuel and non-plastic and fine silt, which is a different composition based on natural coal fuel. Fly ash is one of the waste materials in thermal power plants. It is a byproduct of fuel combustion that is captured and collected by electrostatic precipitators or filter bags (or both) located at the place where furnace exhaust gases exist. The collected ashes are stored compactly until they are moved to a different place [10–14]. This article aims to find out whether substituting volcanic ash for cement works and how oak ash affects concrete, and finally, it aims to introduce a better concrete design [15–19]. In this study, micro volcanic ash was used as one of the best alternatives to cement and oak ash to fill small spaces and reduce the porosity of concrete. The variables are different percentages of micro fly ash used instead of cement and different volumes of oak ash in the mix design. Finally, the produced concrete was tested for consistency parameters, compressive strength, and tensile strength using the indirect (Brazilian) method, and bending strength.

LABORATORY TEST

In the present study, oak bark ash was used due to its abundance in the Kurdistan region, and macro fly ash was used as one of the most widely used pozzolans in the concrete industry. The parameters of concrete and the percentages of materials used in its structure were constants, but different percentages of oak bark ash and macro fly ash were added to the mixed designs. The parameters of concrete density, concrete consistency, compressive strength, tensile strength using the Brazilian method, and bending strength of concrete were investigated. To do this, the existing materials undertook the necessary tests, and based on the obtained data, an optimal concrete mix design was introduced from which the necessary samples were taken.

Then, oak bark ash was used as an additive, in proportions of 0.2 and 0.4%, due to its very low specific weight (315 kg/m^3), by total weight of cement, and macro fly ash was used to replace cement as a variable in various proportions of 5, 10, 15 and 20% (based on prior studies [7]).

Based on the existing variables, together with the control design, a total of 15 groups of mix designs were introduced. The statistical population includes 45 cubic specimens (15×15×15), and 45 cylindrical specimens (15×30) for tensile strength test using Brazilian method, 45 bending beam specimens having dimensions of 10×10×50. Due to the use of Portland cement type 1, nine specimens were taken from each mix design and all specimens had undergone 28 days of necessary tests. It is worth mentioning that a consistency test (slump test) was performed for each mix design at the time of sampling.

Granulation of aggregates

The mix proportions of coarse and fine-grained aggregates have been selected to comply with the grading range specified in ASTM C33.

Cement

The cement used in the concrete design of this study was Portland cement. Portland cement type I-425 of Urmia. It should be noted that the cement used must be completely healthy and its physical and chemical properties must comply with the specifications of AASHTO M85.

Oak bark ash

Due to the abundance of oak in the region and according to previous research on the types of ashes used in the concrete structure, in this study, oak bark ash was used as an admixture in concrete. The oaks used in this study were harvested from the forests around Baneh.

EXPERIMENTAL STUDY

Testing parameters

The parameters of concrete density, concrete consistency, and compressive strength, tensile strength using the Brazilian method, and bending strength of concrete were investigated. To do this, first, the existing materials underwent the necessary tests and according to the resulted data, an optimal concrete mix design was introduced from which the necessary samples were taken. Then, oak bark ash was added to the cement as an admixture where the ratios of added oak bark ash to the weight of cement were 0.2 and 0.4%, and the ratios of macro fly ash, used to replace it as a variable, to the weight of cement were 5, 10, 15 and 20%. Based on the existing variables in general, together with the control design, totally 15 groups of mix designs were introduced. The statistical population includes 45 cubic specimens (15×15×15), and 45 cylindrical specimens (15×30) for tensile strength test using Brazilian method, 45 bending beam specimens having dimensions of 10×10×50. Due to the use of Portland cement type I, nine specimens were taken from each mix design and all specimens had undergone 28 days of necessary tests. It is worth mentioning that a consistency test (slump test) was performed for each mix design, at the time of sampling.

Preparing samples

Determining the mix proportions of aggregates

The results of calculations and studies performed to determine the volume of materials required to produce one cubic meter of concrete with a requested specific strength of B=300kg/cm^2 using the sampled materials and after conducting the necessary tests including granulation, moisture absorption test, the specific gravity and density of aggregates, Los Angeles abrasion test, Sand Equivalent (SE), fineness modulus, the percentage of defective aggregates (flaky and needle-shaped) and material components (chemical test) are given below. The concrete mix design was produced having the following proportions (Table 1). The cubical and cylindrical prepared samples are shown in Figure 1.

Table 1. Percentages of the used aggregates

Sample laboratory number	Specifications of aggregates as stated by the client	Mixing percentage of aggregates
001	Coarse gravel (Almond gravel)	35%
002	Medium gravel (Pea gravel)	13%
003	Fine-grained aggregates (Sand)	52%

Figure 1. Processing of samples produced in a standard environment

Determining the water/cement ratio

Considering the target compressive strength and the environmental conditions to which the concrete structure is exposed, as well as the stability and durability of concrete and its permeability, and considering the technical recommendations of the Iranian Concrete Regulations, in the above design, this amount was considered maximum W/C=0.45.

Final mix design for control samples

Mix proportions of aggregates, cement and water (by weight) in one cubic meter of fresh concrete are listed in Table 2.

The results of different tests are presented in Table 3.

ANALYSIS OF TEST RESULTS

Slump test

As expected, the results of the slump test indicated that the utilization of oak bark ash in the concrete structure reduced concrete consistency, that is, using higher amounts of oak bark in the concrete structure resulted in less concrete consistency. Therefore, it should be noted that in higher percentages, the utilization of oak bark ash required a higher water/cement ratio, or using additives, especially plasticizers. After performing the slump test in all test groups, it can be concluded that due to its microscopic form, macro fly ash increased concrete consistency, but using it together with oak ash reduced its effectiveness. The highest decrease was observed in group 2 of the mix design, which was 21%, and the maximum increase was observed in group 7 of mix design, which was 22%. The maximum variation in the slump test was between group 2 and group 7, that is, 39%.

To sum up, it can be said that, on average, oak bark ash decreased concrete consistency by 17.5% and macro

Table 2. Final mix design for control samples

Water (L)	Oshnaviyeh sand (kg)	Medium gravel (kg)	Coarse gravel (kg)	Weight of cement (kg)
157.5	996	258	652	350

Table 3. The results of slump test, density test, compressive strength test, tensile test and bending strength test

No.	Mix design of concrete	Slump test (cm)	Density test (kg/m^3)	Compressive strength test (MPa)	Tensile strength test (MPa)	Bending strength test (MPa)
1	MD1	7	2454	30.96	2.61	4.62
2	MD2	6	2471	33.04	2.63	4.81
3	MD3	5.5	2486	33.72	2.55	4.94
4	MD4	7.5	2439	33.86	2.93	4.99
5	MD5	8	2421	34.44	3.03	5.18
6	MD6	8	2403	35.59	3.13	5.33
7	MD7	9	2388	33.57	3.01	5.24
8	MD8	7	2462	34.06	2.88	5.14
9	MD9	7.5	2445	35.11	3.01	5.27
10	MD10	8	2428	36.72	3.08	5.44
11	MD11	8.5	2412	35.44	2.95	5.32
12	MD12	6.5	2448	35.17	2.86	5.28
13	MD13	6	2431	36.39	2.91	5.49
14	MD14	6	2419	38.03	3.02	5.38
15	MD15	5.5	2408	37.28	2.83	5.36

fly ash increased concrete consistency by 14.5%. However, these numbers changed when both additives were used simultaneously and when the volume of each additive changed (Figure 2).

Density test

In this study, after weighing and calculating the average weight of the specimens in different groups, it was observed that while using oak bark ash increased the concrete density by an average of 0.9%, macro fly ash, on average, reduced concrete density by 1.6%. In this study, the maximum density variation was observed between groups 3 and 7, which was 3.9% (Figure 3).

Compressive strength test of concrete

The compressive strength test was conducted on cubic specimens at the age of 28 days and the results revealed that, compared to the control specimen, both additives increased the compressive strength of the concrete. The average increase was 7% for oak bark ash and 9.5%. for macro fly ash. Simultaneous application of both additives resulted in better performance so that in group 13. The compressive strength increased by using both additives was 18.5%, which is the highest compressive strength compared to the control specimen (Figures 4 and 5).

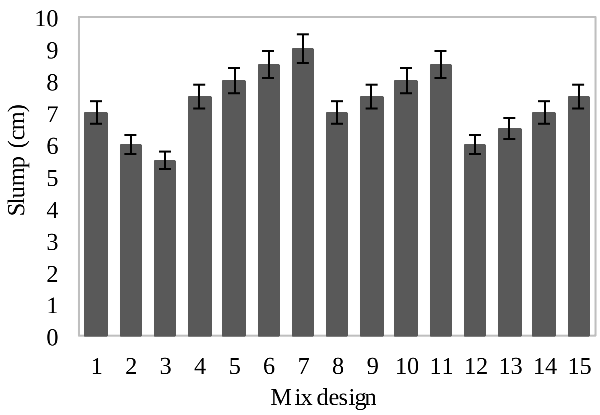

Figure 2. Slump test results

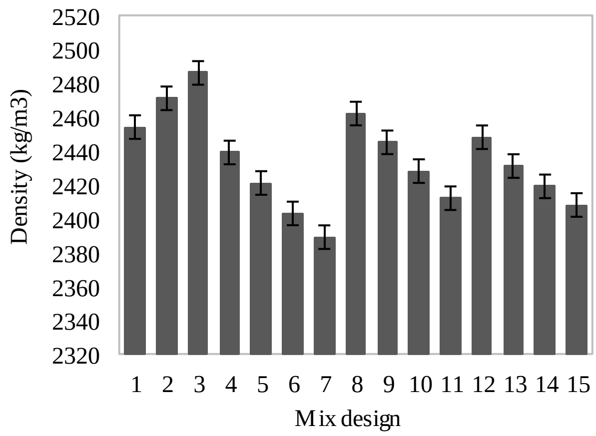

Figure 3. Concrete density test results (ton/m^3)

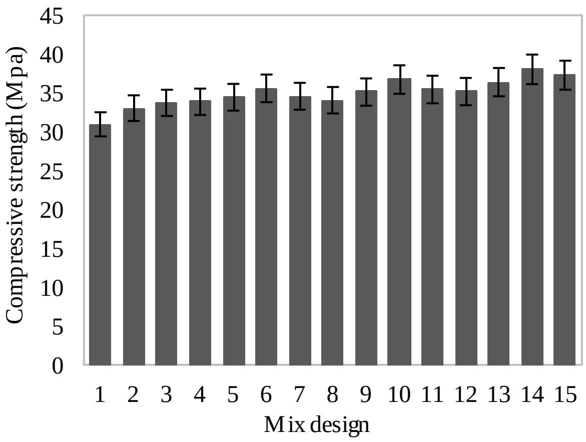

Figure 4. Test results for compressive strength of cubic specimens (15×15×15)

Tensile strength test of concrete

In the present research, oak bark ash had a dual function: when 0.2% of oak bark ash was added to the concrete, the tensile strength of concrete increased by 0.7%, but using more volumes of this additive reduced the tensile strength of concrete by 2.2%. On the other hand, the case differed completely for macro fly ash: its use increased the compressive strength in all groups, and the average rate of this growth was 13.5%. It is worth mentioning that using macro fly ash in amounts higher than 15% lead to a lower performance compared to its previous state.

The test results of this research indicated that macro fly ash and oak bark ash had the least effect on the tensile strength of concrete. The largest difference, i.e. 18%, was between groups 6 and 3. The test results also revealed that if both additives were used simultaneously, the effectiveness of macro fly ash would be higher than that of oak bark ash. We constantly observed an increase in tensile strength compared to the control specimen. Of course, increasing the amount of oak bark ash resulted in the least effectiveness.

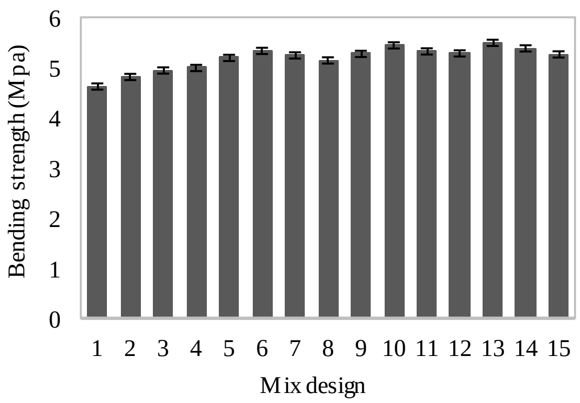

Figure 5. Bending strength test of beam specimens having dimensions of 10×10×50 by MPa

Bending strength test of concrete

The obtained results from the bending strength test indicate that oak bark ash by an average of 7% and macro fly ash by an average of 10.5% increased the bending strength of specimens in different groups. The simultaneous application of both additives has increased their effectiveness so that in group 13 we observed a 16% increase in bending strength compared to the control specimen. This test also revealed that using macro fly ash in amounts over 15% reduces the bending strength of the specimens.

CONCLUSION

After conducting all experiments and comparing their results, it can be concluded that overall, adding oak bark ash and replacing cement with macro fly ash increases the compressive, tensile, and bending strength of concrete. These additives fill the empty spaces inside the concrete structure and reduce concrete porosity and maximize its adhesion. The workability of macro fly ash is better than oak bark ash regarding all three parameters of mechanical properties; on the other hand, it should be mentioned that utilizing macro fly ash in amounts of more than 15% reduces its effect on mechanical properties. Furthermore, using more than the defined amount of oak bark ash decreases adhesion, and adding amounts higher than this has adverse effects on the mechanical properties of concrete. Finally, the improvement of the performance of the specimens in different tests is summarized as follows:

A. 17% reduction in the slump of mix design with oak bark ash as an additive

B. 14% increase in the slump of mix design with macro fly ash as an additive

3. 7% increase in the slump of mix design using both additives

C. 1% increase in the density of mix design with oak bark ash as an additive

D. 1.5% reduction in density of mix design with macro fly ash as an additive

E. 0.5% reduction in density of mix design using both additives

F. 7% increase in compressive strength of mix design with oak bark ash additive

G. 9% increase in compressive strength of mix design with macro fly ash additive

H. 11% increase in compressive strength of mix design using both additives

I. 1.5% reduction in tensile strength of mix design with oak bark ash as an additive

J. 13% increase in tensile strength of mix design with macro fly ash as an additive

K. 11% increase in tensile strength of mix design using both additives

L. 7% increase in bending strength of mix design with oak bark ash additive
M. 10% increase in bending strength of mix design with macro fly ash additive
N. 13% increase in bending strength of mix design using both additives

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Persian Abstract

چکیده

با توجه به افزایش روز افزون کاربرد بتن محققین و مهندسین همواره در تلاشند که بتوانند خواص مکانیکی، فیزیکی و کارایی آن را بهبود ببخشند و بدین منظور از متنوع‌ترین محصولات و مدرن‌ترین تکنولوژی‌های بتن بهره جسته‌اند. در مطالعه حاضر از خاکستر پوست بلوط و خاکستر ماکرو فلای به عنوان یکی از پر رونق‌ترین پوزولان‌ها در صنعت ساخت بتن بهره گرفته شده است. خاکستر پوست بلوط و خاکستر ماکرو فلای به طرح‌های مخلوط اضافه گردیده است، پارامترهای بتن و درصدهای بکارگیری مصالح در ساختار آن ثابت بوده ولی درصدهای مختلف از خاکستر پوست بلوط و خاکستر ماکرو فلای به طرح‌های مخلوط اضافه گردیده است. پارامترهای چگالی بتن، روانی بتن و مقاومت فشاری، مقاومت کششی به روش برزیلی و مقاومت خمشی بتن مورد بررسی قرار گرفته است. بدین منظور ابتدا آزمایشات لازم بر روی مصالح موجود انجام گرفته و با توجه داده‌های کسب شده یک طرح مخلوط بتن بهینه معرفی گردیده و نمونه های لازم از آن اخذ گردید. در ادامه از خاکستر پوست بلوط به عنوان افزودنی به میزان ۰/۲ و ۰/۴ درصد نسبت به وزن سیمان و خاکستر ماکرو فلای میزان ۵، ۱۰، ۱۵ و ۲۰ درصد از وزن سیمان مصرفی جهت جایگزینی آن به عنوان متغیر در نظر گرفته شده است. با توجه به متغیرهای موجود در کل و به انضمام طرح شاهد مجموعاً ۱۵ گروه طرح اختلاط معرفی گردیده و جامعه آماری ۴۵ نمونه‌ی مکعبی ۱۵×۱۵×۱۵ و ۴۵ نمونه استوانه‌ای ۱۵×۳۰ برای آزمون مقاومت کششی به روش برزیلی، ۴۵ نمونه تیر خمشی به ابعاد ۱۰×۱۰×۵۰ تجمیع شد؛ با توجه به استفاده از سیمان پرتلند تیپ ۱ از هر طرح اختلاط ۹ نمونه اتخاذ گردید و تمامی نمونه‌ها پس از عمل‌آوری ۲۸ روزه آزمون‌های لازم به عمل آمده است. شایان ذکر است که در همه‌ی طرح‌های مخلوط و در زمان نمونه‌گیری آزمون روانی بتن (اسلامپ) به عمل آمده است. در نهایت و پس از بررسی داده‌های بدست آمده بهترین عملکرد در طرح مخلوط برتر و اثرگذاری هر دو ماده افزودنی بر روی کلیه پارامترهای مورد مطالعه اعم از روانی بتن، چگالی، مقاومت فشاری، کششی و خمشی بتن مشاهده گردید که خاکستر ماکرو فلای از اثرگذاری بیشتری برخوردار است. همچنین بیان نموده که مصرف بیش از حد هر کدام از افزودنی‌ها می‌تواند اثر منفی بر روی خواص مکانیکی بتن را در بر داشته باشد.